Developing a Risk Breakdown Matrix for the Construction of On-Shore Wind Farm Projects

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ABSTRACT

Wind farm projects have recently gained popularity in many countries. However, since wind farms are a novel type of infrastructure for energy production for which limited historical data are available, numerous unique challenges are encountered during their construction. One of the main challenges involves risk management. Many researchers and practitioners have investigated on- and off-shore wind farm projects in terms of risk identification. However, they have mostly focused on off-shore wind farm projects; there is little research on risk identification for on-shore wind farm projects. To address this gap in the research, this paper develops a risk breakdown matrix (RBM) for the construction of on-shore wind farm projects. Due to a lack of research on risk identification for on-shore wind farm projects, in this paper, the case-based reasoning (CBR) technique is used to develop the RBM. First, the construction work packages (CWPs) of on-shore wind farm projects are identified. Then, by comparing the CWPs of these projects to those from other types of construction projects, the work-package-level risks that affect each CWP are identified based on the similarities between on-shore wind farm projects and other types of construction projects. The RBM developed in this paper can be used for the risk identification and risk management of on-shore wind farm projects. The contributions of this paper are twofold: First, it introduces CBR as a risk identification technique for on-shore wind farm or other similar construction projects, which is a topic that has not previously been comprehensively studied. Second, it identifies the work-package-level risks affecting these projects and maps each risk factor to the affected CWPs.

INTRODUCTION

Since the construction costs of wind farm projects have been decreasing due to technological advancements, these projects are growing in popularity as an efficient way to harness energy from renewable sources (Renewable Energy Policy Network for the 21st Century 2018). As a result, global wind power production capacity increased by 53 GW annually on average from 2013 until 2018, according to the International Renewable Energy Agency (IRENA) report (IRENA 2019). This growth in wind power production capacity is responsible for 30% of the annual growth in global renewable energy production capacity reported from 2013 to 2018 (IRENA 2019). North American countries (i.e., Canada, the USA, and Mexico) produced 16.5% of the annual growth of global wind power capacity, with Canada having added an average of 9 GW annually to their wind power production capacity from 2013 to 2018 (IRENA 2019). Canada and the USA have recently invested in the development of wind farms due to energy demand. As this trend continues, risk management for wind farm projects needs to be investigated in order to reduce the impact of unforeseen events that can affect construction project objectives.

The Project Management Institute (PMI 2016) divides the construction project life cycle into five phases: conception, design, construction, commissioning, and closeout. On wind farm projects, the construction phase consumes the largest portion of project budget and time (Fera et al. 2012). Accordingly, ample research has been conducted on the implementation of risk management procedures for identifying and mitigating the risks that affect wind farm projects during their construction phase (Gatzert and Kosub 2014; Fera et al. 2017). Effective implementation of risk management in the early stages of construction projects is essential for the success of construction projects; failing to properly implement risk management processes can lead to negative impacts on project objectives (Siraj and Fayek 2019). Although risk management for wind farm projects has previously been researched, the majority of existing studies have focused on off-shore wind farm projects. For example, Chien et al. (2013) implemented risk management procedures for an off-shore wind farm in Taiwan, and Gkoumas (2010) developed a risk analysis framework for off-shore wind turbines for the operation and construction phases of these projects. However, there is a gap in the research for identifying risks affecting the construction work packages (CWPs) of on-shore wind farm projects, which is addressed in this paper. This paper aims to identify work-package-level risks and map them to the associated CWPs for on-shore wind farm projects.

Risk identification is the first step in the risk management process, and many tools and techniques have been proposed for this purpose, including case-based reasoning (CBR); literature review; the strengths, weaknesses, opportunities, threats (SWOT) technique; checklist analysis; and diagram analysis (Siraj and Fayek 2019). CBR is a methodology used to identify the characteristics (e.g., risks) of an unknown phenomenon (e.g., an on-shore wind farm project) based on its similarity to other phenomena (e.g., other types of construction projects) by using similar cases to retrieve information about the unknown phenomenon (Watson 1999). CBR can help construction researchers and practitioners identify project risks that are unknown and not well-researched due to their novelty, such as those involved in on-shore wind farm projects. Accordingly, in this paper, due to the lack of comprehensive research on risk identification for on-shore wind farm projects, the CBR technique is used to identify the work-package-level risks that affect these projects during their construction phase. The objectives of this study are twofold. The first objective is to introduce CBR as a risk identification technique for on-shore wind farm projects, and the second is to identify the work-package-level risks affecting these projects and map them to their CWPs.

LITERATURE REVIEW

The International Organization for Standardization (ISO) (2009) defines risk as "the effect of uncertainty on objectives." Construction projects are highly influenced by various risks due to their complex nature and the fact that they are under the influence of numerous external factors (Siraj and Fayek 2019). Therefore, many researchers have aimed to identify or assess risks on construction projects and determine appropriate risk management practices for reducing the adverse effects of risks on construction projects' objectives. Kassem et al. (2019) conducted a survey on the risk factors influencing the oil and gas industry in Yemen, and they identified the risk factors that affect the time and cost of oil and gas projects. Construction risks are traditionally represented in the form of a risk breakdown structure, which is a hierarchical structure of risks categorized based on their potential sources. Hillson et al. (2006) introduced the risk breakdown matrix (RBM) as an innovative format for representing risks on construction projects. In an RBM, risks are presented and each risk is mapped to the work package(s) affected by the risk. RBMs can be presented in the form of matrices or they can be presented graphically in the form of a diagram. Li et al. (2013) developed an RBM for bridge construction projects.

There are a small number of studies in the literature investigating risk identification for wind farm projects. Fera et al. (2017) identified 42 risks for on-shore wind farms; however, they did not specify what risk identification methodology they used. Fera et al. (2017) ranked those 42 risks based on their severity index using the analytic network process, and the result revealed that the quality of concrete curing has a high impact on project objectives. Gatzert and Kosub (2014) investigated the risks affecting on- and off-shore wind farm projects from the design phase until the operation phase and identified 58 risks that are further classified into seven categories, namely business, construction, operation, legal, market, counterparty, and policy risks. As Gatzert and Kosub (2014) mainly focused on off-shore wind farm projects, the majority of the risk factors identified in their study only affect off-shore wind farm projects. Only two of the risks they identified are applicable to both on- and off-shore projects: (1) grid connection and (2) damage to the turbine or theft during transportation or construction. Prostean et al. (2016) used a simulation model to identify risks for on- and off-shore wind farm projects in Romania, identifying 16 risks affecting these projects throughout their life cycles. Delay in completion of turbines by the manufacturer, delay in obtaining construction permits, and lack of qualified labor were found to be the major risks for the construction phase. Finlay-Jones (2007) interviewed eight project managers in Australia who were experts in on- and off-shore wind farm projects and conducted an extensive literature review to identify the risks affecting wind farm projects. They focused primarily on cost risks and validated the list of identified risks through multiple case studies in Australia. Most previous research on identifying the risks affecting wind farm projects has focused on the maintenance and operation phases, rather than on the construction phase. In addition, most research has focused on the risks associated with off-shore rather than on-shore wind farm projects. This paper fills this gap by identifying the work-package-level risks affecting the construction of on-shore wind farm projects.

METHODOLOGY

In this study, CBR is used to identify the risks that affect the construction of on-shore wind farm projects. CBR is a methodology for systematically retrieving information about an unknown phenomenon based on its similarities to other well-studied phenomena, and it has been proven to be an appropriate technique for risk identification (Hu et al. 2016). The most commonly used methodologies for construction risk identification are literature reviews, questionnaire surveys, and interviews (Siraj and Fayek 2019). The literature review methodology relies on the existence of ample research on the same type of construction projects to identify generic construction risks, and questionnaire and interview surveys are highly dependent on subjective expert knowledge. Risk identification using CBR does not rely on expert knowledge or previous research on the same types of construction projects; rather, CBR identifies the risks that affect a specific type of construction project based on its similarities to other types of construction projects. Thus, CBR is an appropriate methodology for risk identification for on-shore wind farm projects since they are novel and there is little research available on risk identification for these types of projects. This section presents the research methodology for implementing CBR for the risk identification of on-shore wind farm projects.

CBR is applied in three key steps: case representation, retrieval, and adaptation (Goh et al. 2009a; Goh et al. 2009b). In the case representation step, the problem case (i.e., risk identification of on-shore wind farm projects) is represented by a set of its characteristics in order to find similar cases. The characteristics used to represent the problem case are identified by considering the scope of the problem, which in this paper is the identification of risks affecting on-shore wind farm projects at the work package level. In the case retrieval step, the represented case is compared to other cases based on its characteristics, which determines the similarities between the problem case and other cases. Cases with similar characteristics are retrieved. While the problem case might not be fully similar to any other cases due to the uniqueness of all construction projects, in the adaptation step, the retrieved cases are analyzed, and the extracted information about these similar cases is modified or removed based on the level of similarity between the problem case and the retrieved cases. The result of the adaptation step is a list of information extracted from the different retrieved cases relevant to the problem case.

Case Representation

In this paper, the characteristics of on-shore wind farm projects used to represent risk identification are the CWPs of on-shore wind farm projects, since the objective of this study is to identify work-package-level risks for on-shore wind farm projects. Representing the problem case by its CWPs leads to the identification of other projects that share the same CWPs. This representation helps extract the work-package-level risks from those similar projects in order to identify the risks that affect the construction of on-shore wind farm projects. Case representation is accomplished by identifying the

CWPs of wind farm projects from the literature based on the scope of research and then representing these projects using their CWPs. Hao et al. (2019) developed a WBS of on-shore wind farm projects by presenting 11 CWPs, namely pre-construction activities, surveying, turbine foundation, turbine assembly, electrical collector line, electrical distribution substation, access road and parking lot, stormwater management system, meteorological tower, dewatering, and O & M building. In this paper, the CWPs used to represent on-shore wind farm projects are adopted from the research conducted by Hao et al. (2019), and three of the CWPs are considered for risk identification using the CBR technique, namely pre-construction activities, metrological tower, and electrical distribution substation.

Case Retrieval

The case retrieval step consists of two sub-steps. First, each CWP is searched in Scopus and the Google Scholar database to find any similar cases. The search in the Scopus database is accomplished by searching for articles that include the name of each CWP and at least one of the four terms (i.e., "risk identification", "risk management", "risk assessment", and "construction risk") within the article keywords, abstract, or title. For Google Scholar, the same keywords are used, but they are searched for within the entire contents of the articles. In addition to scientific articles, technical/engineering reports are also searched in Google Scholar and the Scopus database. The searches in Scopus and Google Scholar are not limited to a specific time frame and/or publisher name. The criteria for selecting similar cases are (1) the article/report specifically identifies construction risks, (2) the article/report lists the work-package-level risk factors, and (3) the defined CWPs are investigated in the article/report in terms of risk identification. These criteria are defined to determine the similarity between the problem case and the other cases using crisp numbers {0, 1}, where 1 means that the case fulfills the three criteria and is considered a similar case and 0 means that the case does not fulfill any of the three criteria and is considered a dissimilar case.

Case Adaptation

In this step, the retrieved articles/reports are reviewed, and the extracted information (i.e., risks) about the similar cases are manually modified or removed based on the dissimilarities between on-shore wind farm projects and the projects studied in the retrieved articles/reports. First, by reviewing each article/report, all risk factors relevant to the CWPs that are common with on-shore wind farm projects are extracted. Next, each risk is analyzed and modified based on similarities and dissimilarities to on-shore wind farm projects. For example, while the meteorological tower is structurally and functionally similar to the telecommunication tower, those risks related to the failure of telecommunication equipment are not relevant to the construction of meteorological towers. Accordingly, this risk factor is modified, and the failure of meteorological tower equipment is considered one of the risk factors that affects on-shore wind farm projects.

CASE STUDY

Three CWPs of on-shore wind farm projects were chosen to represent the problem case, namely pre-construction activities, electrical distribution substation, and meteorological tower. The application of CBR in this study identified 43 work-package-level risk factors affecting the three aforementioned CWPs, shown in Figure

1. For the case retrieval step, Table 1 shows the number of retrieved cases (i.e., construction projects) that share similar CWPs with the on-shore wind farm projects. This section describes each retrieved case in term of its similarity to CWPs.

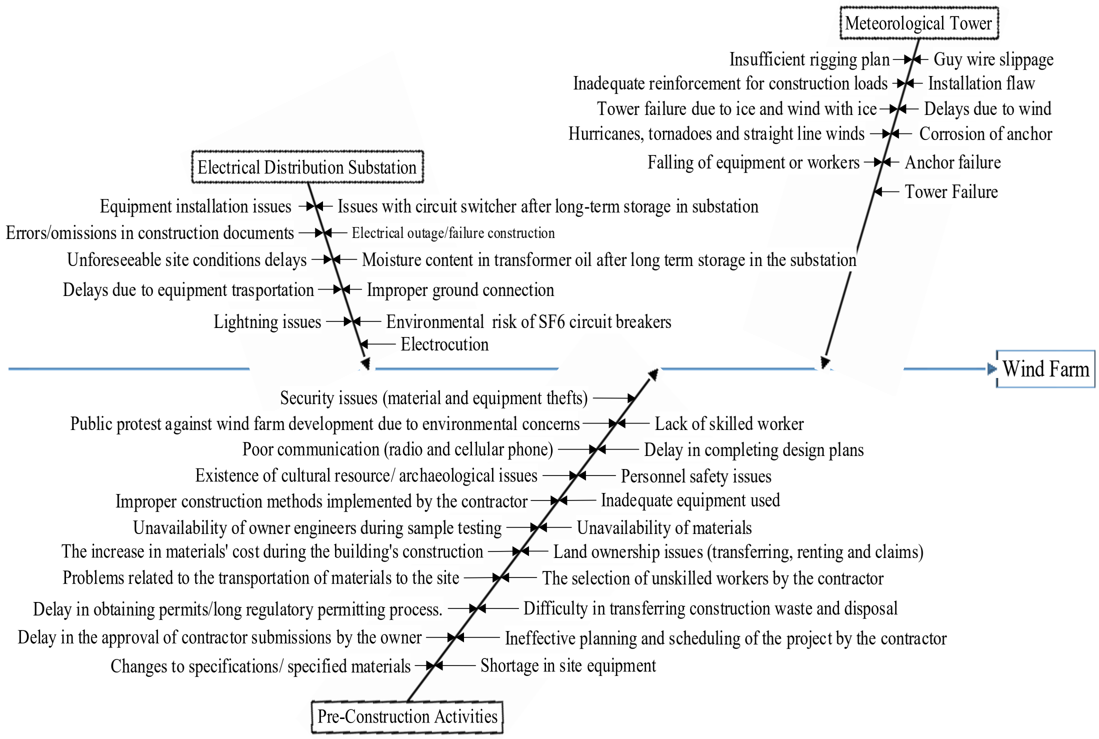

Figure 1. Three CWPs with their associated risk factors.

Table 1. Number of Cases Retrieved by CBR

CWP	Pre-construction activities in remote location	Transmission and distribution (T & D) substation	Hydropower projects	Cell tower	Telecommunication tower
Pre-construction activities	3	0	0	0	0
Electrical distribution substation	0	2	1	0	0
Meteorological tower	0	0	0	1	1

Pre-construction Activities

The first CWP discussed in this paper is pre-construction activities, which consists of different construction activities including site preparation, mobilization, and site acquisition. While pre-construction activities are common between all types of construction projects, this paper focuses on projects operated in remote locations to identify the risk factors affecting this CWP on wind farm projects. On-shore wind farm projects are commonly operated in remote locations, due to social concerns regarding the perceptibility of this type of infrastructure in residential areas; consequently, the pre-construction activities of wind farm projects share many risks with those projects operated in remote locations. Kershaw et al. (2009) studied the risks affecting the construction and design process of water pipeline projects in remote locations and concluded that delays in obtaining permits, the potential to disturb cultural sites, and the existence of security issues are the major risks affecting these projects. Sidawi (2012) identified 22 risks that affect construction projects in remote locations in Saudi Arabia. According to Sidawi (2012), long travel time and lack of construction materials are the major risk factors that affect construction projects in remote locations. Baroudi and McAnulty (2013) did the same investigation on Australian projects and concluded that the lack of skilled workers is the main risk for remote projects in Australia.

Electrical Distribution Substation

The second CWP investigated in this paper for risk identification is the electrical distribution substation. This CWP is common between different types of power plant projects since after the generation of power and its transformation into electricity, the electrical distribution substation is required to distribute the power within the power network. Accordingly, for the identification of risks affecting this CWP, electrical transmission and distribution (T & D) substations were investigated. In addition to generic construction risks that apply to all types of power plant projects, those risks that are specific to renewable energy power plants (e.g., hydropower) projects were investigated, and those risks associated with the construction of electrical distribution substations were extracted. Zhao and Guo (2014) investigated construction risks for ultra-high voltage transmission, which consists of two 1000kV T & D substations and transmission lines. They found that equipment installation and large equipment transportation risks should be considered in the construction phase since they have a greater negative impact on project objectives. The International Association of Engineering Insurers (IMIA) reported that lightning during the construction phase can do serious damage to T & D substations. Stantec (2017) published a report on the construction of a hydropower electrical distribution substation and identified the risk factors that affected the project, namely, error or omissions in construction documents, issues with circuit switchers and moisture content in transformer oil after long-term storage in the substation, delays due to equipment transportation, unforeseeable site condition delays, and electrical outage or failure construction. These risk factors were ranked based on the significance of their impact on project cost.

Meteorological Tower

Meteorological towers commonly have a very high ratio of tower height to tower width (i.e., width measured at the very bottom of the cross-section of towers). Therefore, these types of structures are prone to structural risks caused by horizontal forces (i.e., wind force, earthquakes), and one of the few options available for addressing these risks is to support the structures with structural cables connected to the ground with anchors. The main function of this type of tower is the carriage of measurement instruments. Telecommunication and cell towers have the same functionality and construction method, in that these towers also carry electrical instruments and antennas (i.e., functionality) and are held by anchors and cables (i.e., construction method). Therefore, in this paper, telecommunication and cell towers were investigated in order to identify the risks associated with the construction of meteorological towers for on-shore wind farm projects. Davies (2011) conducted a comprehensive investigation on the main reasons for the failure of cell towers in North America and identified the risks that lead to project failure. The risk factors were insufficient rigging plans, inadequate reinforcement for construction loads, guy wire slippage, tower failure due to ice and wind with ice, and anchor failure and corrosion of anchor. Rosu et al. (2018) searched for the safety risks associated with the installation of telecommunication towers and mentioned that falling is the most severe risk, which leads to worker injury and fatality.

DISCUSSION

Forty-three work-package level risks for on-shore wind farm projects were identified in this study (see Figure 1). The results of this study reveal that of the three CWPs considered for risk identification, pre-construction activities of projects in remote locations is the most highly risk-prone CWP with 21 risk factors. In the comparison of on-shore and off-shore wind farm project risk factors, some risk factors are common in both types of projects (e.g., personal safety issues, lightening issues, and falling of equipment or workers). Although some off-shore wind farm project risk related to marine hazards do not affect on-shore wind farm projects, many risk factors are common to both types of projects due to their remoteness.

CONCLUSIONS

Risk identification for on-shore wind farm projects has not yet been thoroughly researched due to the novelty of these projects, even though there is a need to identify the risks that affect these projects so they can be effectively managed. In this paper, CBR is used as a technique for risk identification for on-shore wind farm projects to overcome the lack of research on these projects. The application of CBR in this paper identified 43 work-package-level risks that affect on-shore wind farm projects during the construction phase. The results of this research show that CBR is an appropriate method for risk identification for any novel type of construction project that has not been comprehensively researched or for risk management practices on those projects that suffer from a lack of historical data. The results of this study can also be used as a general source for researchers and practitioners for risk identification for on-shore wind farm projects. In future research, all the work-package-level risks that affect the construction of on-shore wind farm projects will be identified. These risks will be prioritized based on their severity using multi-criteria decision-making (MCDM) techniques. MCDM techniques (e.g., the analytic hierarchy process) can be used to prioritize work-package-level risks based on their severity with regard to project objectives. In addition, the fuzzy similarity index can be used instead of crisp values to measure similarity. In this paper, crisp values for similarity measurement are used: each case is either similar or not similar, and cases that are partially similar to the problem case are overlooked. This limitation can be addressed by using a fuzzy similarity index, which can consider partial similarity between the problem case and other cases using any number within the range of [0,1] in order to retrieve more information about the problem case.

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